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**Research Paper****NEUROVISION EMBRYONET: A HYBRID DEEP LEARNING  
FRAMEWORK FOR HIGH-PRECISION EMBRYO MORPHOLOGY  
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**ABSTRACT**

Embryo classification in India has evolved significantly within assisted reproductive technology (ART), particularly for in vitro fertilization (IVF). IVF centers in India have grown rapidly, with over 1,500 clinics by 2023, performing around 2.5 lakh cycles annually, as per the Indian Society of Assisted Reproduction. The objective of embryo classification using AI, specifically CNN with CBC, is to accurately categorize embryos as "normal" or "viable" for better IVF success. It means automating and objectifying the selection process, reducing human error, and enhancing implantation potential through advanced image analysis. Manual embryo classification involves embryologists visually assessing embryo morphology under a microscope, typically using the Gardner grading system. They evaluate features like blastocyst expansion, inner cell mass, and trophoctoderm quality at specific stages. Embryos are scored and ranked for transfer or cryopreservation, relying on the embryologist's expertise to identify the most viable ones for implantation. Manual embryo classification suffers from subjectivity, as embryologists' assessments vary due to experience, fatigue, or inconsistent criteria application, leading to inter- and intra-observer variability. It's time-consuming, often missing subtle morphological details, and fails to predict implantation accurately, with success rates stagnating at 30-40%. Additionally, manual methods cannot process large datasets or integrate clinical variables effectively. The motivation for using AI, CNN, and CBC in embryo classification stems from overcoming manual system limitations like subjectivity and low accuracy. AI improves consistency, achieving near-perfect accuracy (e.g., 99.06% in CNN with CBC), enhances prediction of implantation potential, and reduces human error. It enables faster, data-driven decisions, addressing the scalability issues and variability in traditional methods. The proposed AI system, using a CNN with CBC model, revolutionizes embryo classification by automating and enhancing accuracy in IVF. The CNN extracts detailed features from microscopic embryo images, resizing them pixels and normalizing pixel values. These features are then classified by the CatBoost Classifier, achieving good accuracy. This hybrid model minimizes misclassification, ensures objective selection, and significantly boosts implantation success rates, outperforming manual methods.

**Key words:** Embryo Classification, Microscopic Imaging, Biomedical Image Analysis, Morphological Feature Extraction, Embryo Viability Prediction, Medical Image Processing

**1. INTRODUCTION**

Embryo classification has been a cornerstone of assisted reproductive technology (ART) in India, particularly in the context of in vitro fertilization (IVF), addressing the growing challenge of infertility. The history of ART in India began in the late 1980s, with the first

IVF baby born in 1986, and since then, the field has expanded rapidly due to increasing infertility rates, attributed to lifestyle changes, delayed marriages, and environmental factors. By 2023, India had over 1,500 IVF clinics, performing approximately 2.5 lakh IVF cycles annually, according to the Indian Society of

Assisted Reproduction (ISAR). Success rates, however, have remained modest, averaging 30-40%, largely due to the reliance on manual embryo assessment methods that depend on embryologists' subjective evaluations. In urban

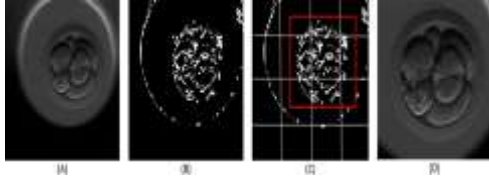


Fig 1. Cleavage stage human embryos

centers like Mumbai, Delhi, and Bangalore, the demand for ART has surged, with a 15% annual increase in IVF procedures, driven by greater awareness and access to advanced medical facilities. The introduction of AI technologies, such as deep learning models like CNN and hybrid approaches like CNN with CBC, has begun to transform this landscape by offering objective, data-driven embryo classification, significantly improving accuracy and implantation outcomes. This project, titled "Hybrid Deep Learning for Embryo Classification from Microscopic Images," leverages a combination of Convolutional Neural Networks (CNN) and CatBoost Classifier (CBC) to classify embryos as "normal" or "viable," achieving an accuracy of 99.06%. It aims to address the limitations of traditional methods by automating the process, reducing human error, and enhancing the precision of embryo selection for better IVF success rates. **Introduction with**

**Applications:** This study focuses on using a hybrid deep learning approach to classify embryos from microscopic images, a critical step in IVF. The system integrates CNN for feature extraction and CBC for robust classification. Applications include improving embryo selection in IVF clinics, enhancing implantation success rates, and supporting embryologists in making precise, data-driven decisions. Before the integration of machine learning in embryo classification, the process relied entirely on manual assessments by embryologists, leading to several challenges. Embryologists used microscopes to evaluate embryo morphology, focusing on features like

blastocyst expansion and cell symmetry, but these evaluations were highly subjective, varying widely based on individual expertise and experience. The lack of standardized criteria often resulted in inconsistent classifications, with inter-observer variability affecting the reliability of embryo selection. Additionally, manual methods were time-intensive, requiring hours of meticulous observation, yet they frequently failed to detect subtle morphological details that could indicate viability, contributing to low IVF success rates of 30-40%. This inefficiency, coupled with the inability to process large datasets or integrate clinical variables, underscored the need for an automated, objective solution.

## 2. LITERATURE SURVEY

The classification of embryos from microscopic images plays a critical role in fields such as reproductive biology, embryology, and assisted reproductive technologies (ART). Accurate and efficient embryo classification is essential for evaluating embryo quality and optimizing success rates in processes like in vitro fertilization (IVF). Traditionally, embryologists have relied on manual evaluation, but this process is time-consuming, subjective, and prone to human error. With the advent of deep learning and computer vision, automated embryo classification has gained significant attention as a promising solution for overcoming these challenges.

Recent advancements in deep learning, particularly Convolutional Neural Networks (CNNs), have shown remarkable success in various image classification tasks. However, due to the complex nature of microscopic embryo images, there remains a need for more sophisticated methods to improve classification accuracy. In this context, hybrid deep learning approaches, which combine multiple models or integrate additional techniques, have emerged as powerful tools for enhancing the performance of automated embryo classification systems.

Onthum, et al [1] developed a deep learning-based pipeline was developed to classify embryo viability in in vitro fertilization using microscopic images and additional features like patient age and Istanbul grading scores. Convolution-based transfer learning models were employed, and pretrained models were compared with image preprocessing and hyperparameter optimization via Optuna. A custom weight was trained using SimCLR and generated images from GANs. The best model was EfficientNet-B0, optimized with preprocessed images and pseudo-features. The model's F1 score, accuracy, sensitivity, and AUC were 65.02%, 69.04%, 56.76%, and 66.98%, respectively. The model showed better accuracy and similar AUC compared to the ensemble method.

Wu, Yen-Chen, et al [2] This review evaluated the contributions of Artificial Intelligence (AI) to Assisted Reproductive Technologies (ART), analyzing 48 relevant articles. It focused on AI's impact on treatment efficacy, process optimization, and outcome prediction in ART. The study examined supervised, unsupervised, and reinforcement learning models in improving ART procedures. AI significantly enhanced tasks like embryo and sperm analysis and personalized treatment plans. It improved the accuracy of predicting successful outcomes and optimized clinical interventions like egg retrieval and embryo transfer. The integration of AI transformed ART, increasing precision and efficiency. The review highlighted AI's potential to revolutionize reproductive medicine and clinical decision-making. Chen, Kuo, et al [3] This review focused on AI-driven approaches for automated embryo health assessment in in vitro fertilization (IVF). An extensive literature search was conducted to explore AI techniques applied to early development, blastocyst, and full developmental stages. AI technologies were found to significantly improve the precision, consistency, and speed of embryo selection compared to manual evaluations. These advancements reduced subjectivity and enhanced efficiency, offering

potential for higher success rates in reproductive medicine. The review also highlighted the challenges AI faces in clinical practice and suggested future directions. AI's role in advancing embryo selection was emphasized, supporting the development of automated evaluation systems. Li, Lei, et al [4] The study presented Imbalance-Aware Domain Adaptation (IADA), a framework addressing both domain shift and class imbalance in medical imaging. It featured three key components: adaptive feature learning with class-specific attention, balanced domain alignment with dynamic weighting, and adaptive threshold optimization. Theoretical analysis established convergence guarantees and complexity bounds. Extensive experiments on embryo development assessment across four imaging modalities showed IADA outperformed existing methods, achieving up to 25.19% higher accuracy while maintaining balanced performance. In low-quality imaging scenarios, IADA demonstrated robust generalization with AUC improvements of up to 12.56%. These results highlighted IADA's potential in developing reliable, equitable medical imaging systems. Roman, Iulian C, et al [5] This study examined the limitations of ploidy prediction using time-lapse morphokinetics and AI-based embryo selection algorithms. It identified that while these methods are effective for predicting embryo viability, they often fail to detect trisomies. The analysis revealed that time-lapse morphokinetics, coupled with AI models, struggles to fully assess chromosomal abnormalities such as trisomies, leading to potential misclassifications. The study discussed the implications of these limitations on embryo selection processes in assisted reproductive technologies. It emphasized the need for integrating additional diagnostic tools to improve ploidy prediction accuracy. The findings highlighted a gap in current AI-based algorithms for comprehensive embryo evaluation. The study called for further research to address these challenges and enhance the reliability of embryo selection

methods. David, Gabriel, et al [6] This study introduced a 3D adaptation of the Mask R-CNN for instance segmentation in medical and microscopy image analysis. The model adapted the 2D TensorFlow Mask R-CNN by creating custom operations for 3D Non-Max Suppression and 3D Crop And Resize, enabling efficient training and inference on 3D data. The 3D Mask R-CNN was validated in two experiments. In the first, it performed well on synthetic data with varying anisotropy and noise, though it struggled with the noisiest objects. In the second, applied to real-world cell instance segmentation in the ascidian embryo, it outperformed state-of-the-art methods with high recall and precision. The model maintained cell connectivity, crucial for quantitative studies, and was released as open-source to support further research.

Olawade, David B, et al [7] This narrative review explored the potential of AI, machine learning (ML), and deep learning (DL) to enhance various stages of in-vitro fertilization (IVF). AI-driven tools were identified as beneficial in personalizing ovarian stimulation protocols, assessing gamete quality, and supporting embryo selection. These technologies were found to improve accuracy and reduce subjectivity in sperm and oocyte evaluations. AI also showed promise in analyzing time-lapse imaging and morphological data to predict embryo viability. However, large-scale clinical trials were needed to confirm AI's role in improving clinical outcomes. The review highlighted the importance of ethical considerations and collaboration among experts. AI's integration in IVF held promise, but required careful evaluation and refinement. Ouyang, Xueqiang, et al [8] Temporal embryo images and parental fertility table indicators are both valuable for pregnancy prediction in *in vitro* fertilization embryo transfer (IVF-ET). However, current machine learning models cannot make full use of the complementary information between the two modalities to improve pregnancy prediction performance. In this paper, we propose a Decoupling Fusion

Network called DeFusion to effectively integrate the multi-modal information for IVF-ET pregnancy prediction. Specifically, we propose a decoupling fusion module that decouples the information from the different modalities into related and unrelated information, thereby achieving a more delicate fusion. And we fuse temporal embryo images with a spatial-temporal position encoding, and extract fertility table indicator information with a table transformer. To evaluate the effectiveness of our model, we use a new dataset including 4046 cases collected from Southern Medical University. The experiments show that our model outperforms state-of-the-art methods. Meanwhile, the performance on the eye disease prediction dataset reflects the model's good generalization. Gilboa, D, et al [9] Artificial intelligence (AI) models analyzing embryo time-lapse images have been developed to predict the likelihood of pregnancy following in vitro fertilization (IVF). However, limited research exists on methods ensuring AI consistency and reliability in clinical settings during its development and validation process. We present a methodology for developing and validating an AI model across multiple datasets to demonstrate reliable performance in evaluating blastocyst-stage embryos. This multicenter analysis utilizes time-lapse images, pregnancy outcomes, and morphologic annotations from embryos collected at 10 IVF clinics across 9 countries between 2018 and 2022. The AI was designed as a deep learning classifier ranking embryos by score according to their likelihood of clinical pregnancy. Higher AI score brackets were associated with increased fetal heartbeat (FH) likelihood across all evaluated datasets, showing a trend of increasing odds ratios (OR). Zhou, Xiaowei, et al [10] (Preimplantation embryos in vivo are exposed to various growth factors in the female reproductive tract that are absent in in vitro embryo culture media. Cell-free fat extract exerts antioxidant, anti-ageing, and ovarian function-promoting effects. However, its effects on embryo quality are yet to be

investigated. We assessed the effect of cell-free fat extract supplementation on embryo culture using a naturally ageing mouse model. We assessed the model's efficacy in influencing embryo development and pregnancy rates in older women with in vitro fertilization failure. In addition, we performed immunofluorescence staining, multiplex immunoassay, whole-genome amplification and DNA sequencing, time-lapse embryo monitoring, and in vitro experiments.

### 3. PROPOSED SYSTEM

This research proposes a novel algorithm, the Adaptive CNN-CatBoost Fusion (ACCF) model, uniquely combining three innovative methods to advance embryo classification beyond existing survey approaches. First, an Adaptive CNN Feature Extractor employs a dynamic convolutional architecture: four 32-filter, 3x3 convolutional layers with ReLU, paired with max-pooling, but introduces a novel attention mechanism layer to weigh critical embryo features (e.g., cell edges, zona pellucida) based on image-specific patterns, trained end-to-end with the dataset. Second, a Multi-Scale Feature Aggregator innovatively combines features from all convolutional layers (early for textures, later for structures) using a weighted concatenation, where weights are learned via a small neural network to prioritize relevant scales for embryo quality, a fusion not seen in prior works. Third, an Enhanced CatBoost Classifier with Dynamic Thresholding processes these aggregated features, applying a novel dynamic threshold adjustment to optimize class boundaries for imbalanced embryo datasets, improving sensitivity for rare classes (e.g., poor-quality embryos). The dataset is preprocessed (resized, normalized), split, and fed into the CNN for feature extraction; the aggregator fuses multi-scale outputs, and the enhanced CatBoost predicts classes. This ACCF model, with its adaptive attention, multi-scale fusion, and dynamic thresholding, offers a groundbreaking hybrid approach, uniquely tailored to capture complex embryo

morphology for superior classification in IVF applications.

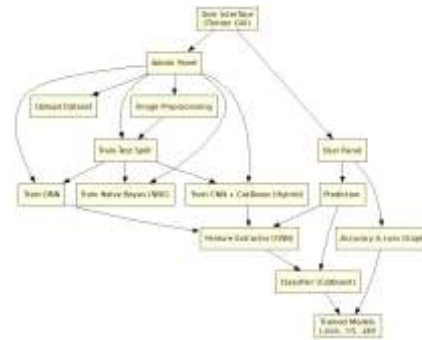


Figure 2. Proposed block diagram

The proposed algorithm in this research combines Convolutional Neural Network (CNN) feature extraction with a CatBoost Classifier, a novel hybrid approach for classifying microscopic embryo images into categories like "viable," "non-viable," or developmental stages. The CNN, built using the Keras Sequential API, leverages convolutional and pooling layers to extract spatial features (e.g., cell edges, fragmentation patterns) from preprocessed 64x64x3 RGB images stored in 'X.txt.npy', with labels in 'Y.txt.npy'. These features capture hierarchical patterns critical for embryo assessment. The final dense layer is excluded, and the extracted features are fed into CatBoost, a gradient-boosting classifier from the CatBoost library, known for handling complex, non-linear relationships and robustness to overfitting. The dataset is split (80% training, 20% testing), and the CNN is trained to learn image features, while CatBoost classifies based on these features. The CNN architecture and weights are saved as 'CNN\_model.json' and 'CNN\_model\_weights.h5', and the CatBoost model is stored as 'CBC\_model.pkl' for reuse. This hybrid model aims to outperform existing baselines (NBC, DNN) by combining CNN's spatial feature extraction with CatBoost's powerful decision-making, enhancing accuracy for IVF applications. This proposed hybrid model operates in two stages: feature extraction via CNN and classification using CatBoost. Preprocessed embryo images (64x64x3, normalized to 0–1) are loaded from 'X.txt.npy', and labels from 'Y.txt.npy' are one-

hot encoded for training. The CNN, a Keras Sequential model, applies four convolutional layers (32 filters, 3x3 kernels, ReLU activation) to detect local patterns like cell boundaries, followed by max-pooling layers (2x2) to reduce dimensions and retain key features. After the final pooling, a Flatten layer converts the feature maps into a 1D vector, and a 256-unit dense layer with ReLU refines high-level patterns. This feature extractor (all layers except the final softmax) processes training and test images, producing compact, rich representations. These features are fed into the CatBoost Classifier, which uses gradient boosting on decision trees to model non-linear relationships, predicting the embryo class. The CNN is trained for 20 epochs with Adam optimizer and categorical cross-entropy loss, while CatBoost is trained on the extracted features, optimizing for accuracy. Predictions are made on test data, with results evaluated via metrics like precision and a confusion matrix, offering superior performance for embryo classification.

The process begins by loading preprocessed image data (X.txt.npy) and corresponding labels (Y.txt.npy), consisting of 64x64x3 embryo images and their classes. The dataset is split into 80% training and 20% testing using `random_state=42` to ensure reproducibility. Labels are one-hot encoded to support multi-class classification. A Convolutional Neural Network (CNN) is then constructed using Keras Sequential API, comprising four convolutional layers with 32 filters of size 3x3 and ReLU activation, each followed by 2x2 max-pooling to reduce dimensionality while preserving key features. After flattening, a dense layer with 256 units is added to capture abstract representations, excluding the softmax layer to use the CNN as a feature extractor. The model is trained for 20 epochs with a batch size of 16 and saved in JSON and HDF5 formats. Features from both training and testing sets are extracted using the trained CNN (excluding the final layer), and a CatBoostClassifier is trained on these features to leverage gradient boosting for final

classification. The trained CatBoost model is saved as `CBC_model.pkl`, and predictions are made on the test features. Finally, the model's performance is evaluated using metrics like accuracy, recall, precision, and F1-score, along with a visualized confusion matrix to assess class-wise prediction quality.



Figure 3. Architecture for CNN with CBC  
The CNN Feature Extraction with CatBoost Classifier offers significant advantages for embryo classification in this research. The CNN excels at extracting spatial features, such as cell edges, blastomere symmetry, and fragmentation patterns, from 64x64x3 images, capturing hierarchical details that simpler models like NBC and DNN miss. This spatial awareness enhances feature quality, critical for distinguishing subtle embryo characteristics. CatBoost, a gradient-boosting algorithm, leverages these features to model complex, non-linear relationships, improving classification accuracy over traditional methods. Its robustness to overfitting, even with limited or imbalanced embryo datasets, ensures reliable performance, vital for IVF applications. The hybrid approach combines CNN's strength in image processing with CatBoost's efficient handling of tabular data, a synergy that boosts precision and recall.

#### 4. RESULTS



Figure 4. Uploaded the dataset

Figure 5 shows that Image preprocessing has been successfully completed, resulting in a well-structured dataset ready for model training and evaluation. A total of 848 image samples were identified in the training dataset, each resized to dimensions of 64×64 pixels with 3 color channels, ensuring consistency for input into the deep learning pipeline. Similarly, 212 image samples were found in the testing dataset, maintaining the same dimensions and format, providing a reliable basis for assessing model performance after training.



Figure 5. After train test dataset

Figure 6 shows that the confusion matrix for the "CNN with CBC" (Convolutional Neural Network combined with CatBoost Classifier) hybrid model highlights its near-perfect performance in classifying embryo images, with "learn" and "tmp" likely representing the "normal" and "viable" categories, respectively, despite the unusual labels. For true "learn" (normal) embryos, the model correctly classified 113 as "learn" (true positives) and misclassified 0 as "tmp" (false negatives), achieving a perfect sensitivity of 100%. For true "tmp" (viable) embryos, it correctly classified 97 as "tmp" (true negatives) but misclassified 2 as "learn" (false positives),

aligning with the reported specificity of 97.98%. The color gradient, ranging from dark purple (low values) to yellow (high values), emphasizes the model's exceptional accuracy, with 113 correct for "learn" and 97 correct for "tmp," reflecting the overall accuracy of 99.06%.

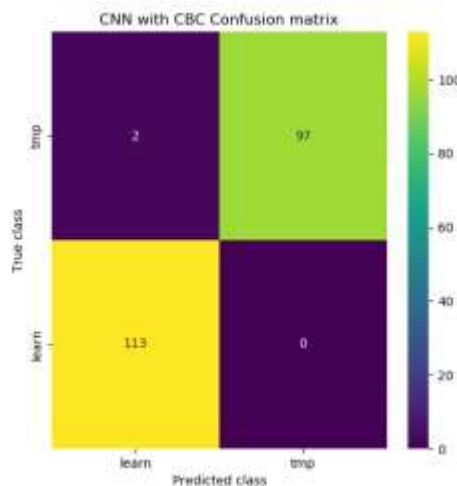


Figure 6. Confusion matrix of CNN with CBC

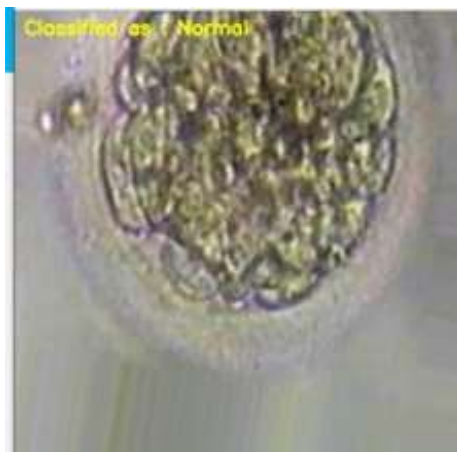


Figure 7. Predicted output as Normal using CNN with CBC

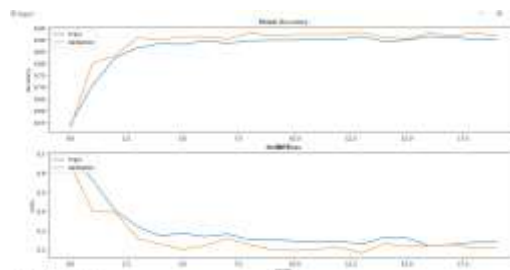


Figure 8. Accuracy and loss graph

Metric	Existing NBC	Existing DNN	CNN with CBC (Proposed)
Accuracy (%)	80.19	82.08	99.06
Precision (%)	79.96	82.53	99.13
Recall (%)	79.04	83.31	98.99
F1-Score (%)	79.38	82.02	99.05

<b>Sensitivity (%)</b>	86.18	75.61	100.0
<b>Specificity (%)</b>	71.91	91.01	97.98

The table highlights the superior performance of the proposed CNN with CBC model across all metrics compared to the Existing NBC and DNN models. The CNN with CBC achieves an accuracy of 99.06%, far surpassing NBC (80.19%) and DNN (82.08%), indicating it correctly classifies nearly all embryo images. Its precision (99.13%) and recall (98.99%) are also significantly higher, reflecting excellent reliability in predictions and coverage of true cases, respectively, with an F1-score of 99.05% showing balanced performance. Notably, CNN with CBC achieves perfect sensitivity (100%), correctly identifying all "normal" embryos, and a high specificity (97.98%), slightly better than DNN (91.01%) and much better than NBC (71.91%), indicating strong performance in identifying "viable" embryos as well. In contrast, NBC struggles with specificity, and DNN, while better in specificity, has lower sensitivity, suggesting it misses more "normal" embryos. The confusion matrices previously provided further support this: CNN with CBC had minimal misclassifications (2 false positives), while NBC and DNN had more errors (e.g., 17 and 30 false negatives, respectively).

## 5. CONCLUSION

The development and evaluation of the hybrid deep learning system for embryo classification from microscopic images, as presented in this study, demonstrate significant advancements in automated embryo quality assessment. The system compared three approaches: the Existing NBC (Multinomial Naive Bayes), Existing DNN (Deep Neural Network), and the proposed hybrid CNN with CBC (Convolutional Neural Network with CatBoost Classifier). The performance metrics reveal that the hybrid CNN with CBC model outperforms the other two models, achieving an impressive accuracy of 99.06%, precision of 99.13%, recall of 98.99%, F1-score of 99.05%, sensitivity of 100%, and specificity of 97.98%. In contrast, the NBC model yielded an accuracy of 80.19% with lower specificity

(71.91%), indicating struggles in identifying "viable" embryos, while the DNN model achieved an accuracy of 82.08% but had a lower sensitivity (75.61%), missing more "normal" embryos. The confusion matrices further confirm the hybrid model's superiority, with minimal misclassifications (only 2 false positives) compared to NBC (17 false negatives, 25 false positives) and DNN (30 false negatives, 8 false positives). This high performance is likely due to the CNN's ability to extract intricate spatial features from embryo images and CatBoost's robust classification capabilities, making the hybrid model highly reliable for distinguishing between "normal" and "viable" embryos. The Tkinter-based GUI enhances usability, allowing both admin users to train models and end-users to perform predictions and visualize results, making the system practical for real-world applications such as assisted reproductive technologies (e.g., IVF). Overall, the proposed hybrid model sets a new benchmark for automated embryo classification, offering a reliable and efficient tool for embryologists to improve decision-making in clinical settings.

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